International Workshop on e+e- collisions from Phi to Psi 2013

PHI PSI 13

Rome, 9th -12th September 2013

"Sapienza" University - Physics Department

Status of Monte Carlo generators for gamma-gamma physics

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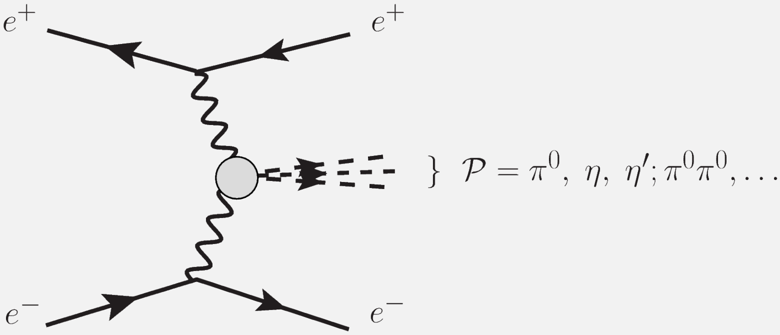
Outline

- ✓ Intro to $\gamma^*\gamma^*$ physics
- ✓ Monte Carlo for $\gamma^*\gamma^*$
- ✓ Rad.corrs
- ✓ Summary

Gamma-gamma production



- two photons are being exchanged in *t*-channel

Reviews of gamma-gamma physics

[Terazawa, Rev.Mod.Phys. 45 (1973) 615]

[Budnev, Ginzburg, Meledin, Serbo, Phys.Rep. 15 (1975) 181]

[Wagner, "Photon photon reactions" (1983)]

[Berger, Wagner, Rev.Mod.Phys. 146 (1987) 1]

- main physics problems
- basic formulae
- equivalent photon approxiamtion (EPA)
- basic experimental approaches ("single-tag", "double-tag")

Physics highlights

production of hadrons

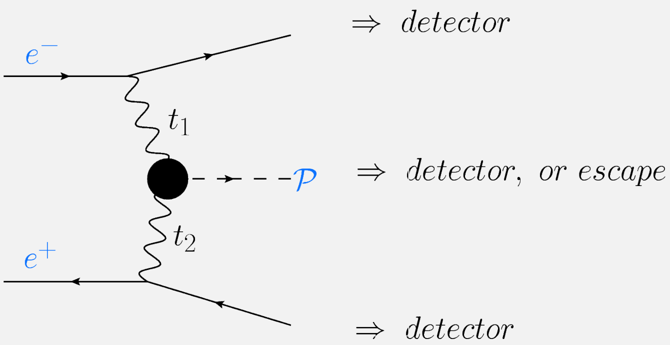
- Adler-Bell-Jackiw anomaly ($\gamma^*\gamma^* \to$ odd number of pseudoscalars)
- continuum study ($\gamma^*\gamma^* \to$ pair of mesons)
- scalar and tensor mesons
- meson mixing, symmery breaking patterns
- polarizabilities

...

production of other particles

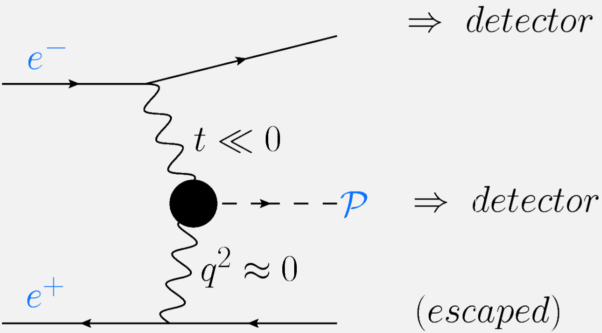
- new particle searches ($\gamma^*\gamma^* \to X$)
- QED studies ($\gamma^*\gamma^* \to \mu^+\mu^-$)

Gamma-gamma experiment. Double-tag



- detecting (tagging) both leptons
  access to both variables: t_1 and t_2

Gamma-gamma experiment. Single-tag



- tagging one lepton
  measure only one invariant, $Q^2 = -t$

Different regions of interest

large $\sqrt{s}$

- good EPA, high σ
- low BG from annihilation channel

small $\sqrt{s}$

This is where we live "from ϕ to ψ"

- poor EPA, small σ
- BG from annihilation channel

Phenomenology depends on the scale of $\sqrt{s}$

Gamma-gamma physics in this talk

Gamma-gamma production of hadrons

exclusive particle production via the *photon-photon fusion* sub-process of the e^+e^- scattering.

$e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\mathcal{P}$

Focus on

- small $\sqrt{s}$ (up to few GeV)
- one, two, at most three particles produced

Physics context

Two-photon transition form factors

- Shape, slope

  [Czyż, Ivashyn, Korchin, Shekhovtsova, Phys.Rev. D85 (2012) 094010]

- Asymptotics ("the BaBar puzzle")

  [Dorokhov, JETP Lett. 92 (2010) 707]

  [Bakulev, Mikhailov, Pimikov, Stefanis, Phys.Rev. D86 (2012) 031501, D87 (2013) 094025]

- Impact on muon $g - 2$
  (hadronic light-by-light scattering)

  [Jegerlehner, Nyffeler, Phys.Rep. 477 (2009) 1]

  [Babusci et al., Eur.Phys.J. C72 (2012) 1917]

  [Zhevlakov, Radzhabov, Dorokhov, Russ.Phys.J. 53 (2010) 625]

@ PhiPsi 13

Recent/ongoing/planned data analyses

See today's talks

D.Babusci — KLOE/KLOE-2 $\sqrt{s} \approx 1.02$ GeV

- $\mathcal{P} = \pi^0, \pi^0\pi^0, \eta$

S.Uehara — BELLE $\sqrt{s} \approx 10.58$ GeV

- $\mathcal{P} = \pi^0, \pi^0\pi^0, \pi^+\pi^-, \pi^0\eta, K\bar{K}$

On Thursday

X.Song — BES-III $\sqrt{s} \approx 3.77$ GeV

- $\mathcal{P} = \pi^0, \eta, \eta'$

Main requirements for MC

- High efficiency under a typical event selection
- Realistic phenomenology
- Realistic QED radiative corrections

MC used in experiments

The collaborations typically use their pivate MC

- KLOE (a MC by Nguyen, Piccinini and Polosa)
- CLEO (TwoGam by D.Coffman / V.Savinov)
- Belle (TREPS by S.Uehara)
- BES-III (UDOD by V.Bytev and A. Zhemchugov and TwoGam from DELPHI)

Lately: publicly available MC generators (via CPC)

- KLOE-2, BES-III (EKHARA)
- BaBar (GGRESRC)

Available MC: small $\sqrt{s}$ I

GGRESRC

[Druzhinin, Kardapoltsev, Tayursky, arXiv:1010.5969, to appear in CPC (2013)]

- $\gamma\gamma^* \to \pi^0, \eta, \eta', \eta_c$
- simple VMD form factors
- rad.corrs according to modified prescription of

  [Ong, Kessler, Phys.Rev. D38 (1988) 2280]

  [Ong, Carimalo, Kessler, Phys.Lett. B142 (1984) 429]

Available MC: small $\sqrt{s}$ II

EKHARA

`http://prac.us.edu.pl/~ekhara`

[Czyż, Ivashyn, Comput.Phys.Commun., 182 (2011) 1338]

- $\gamma^*\gamma^* \to \pi^0, \eta, \eta'$
- custom, fine-tuned form-factors

  [Czyż, Ivashyn, Korchin, Shekhovtsova, Phys.Rev. D85 (2012) 094010]
- rad.corrs not public yet

Available MC: large $\sqrt{s}$ I

GALUGA

[Schuler, Comput.Phys.Commun., 108 (1998) 279]

- $\gamma^*\gamma^* \to \ldots$ (30 mesons)
- Based on *Budnev formalism*

  [Budnev, Ginzburg, Meledin, Serbo, Phys.Rep. 15 (1975) 181]

- models for $\gamma^*\gamma^* \to \ldots$

  ✓ const. quark model

  ✓ VMD

  ...
- no rad.corrs
- highly effective mapping

Available MC: large $\sqrt{s}$ II

GaGaRes

[Berends, von Gulik, Comput.Phys.Commun., 144 (2002) 82]

- $\gamma^*\gamma^* \to {}^1S_0\ (0^-), {}^3P_J\ (J^+)\ (J = 0, 1, 2), {}^1D_2(2^-)$ resonances of u, d, s, c, b quarks
- Based on *Density matrix formalism* (hard scattering)

  [Schuler, Berends, van Gulik, Nucl. Phys. B 523 (1998) 423]
- no rad.corrs
- special mapping for no-tag, single-tag and double-tag

Available MC: large $\sqrt{s}$ III

- the phenomenology can be not appropriate for small $\sqrt{s}$ physics
- the algorithms can teach us a lot

GALUGA mappings $\Rightarrow$ *GGRESRC*, *EKHARA*

Types of rad.corrs

Leading corrections

- virtual correction to the vertex
- soft photon emission
- hard photon emission
- self energy / vacuum polarization
- box diagrams (extra photon exchange)

Standard approach to rad.corrs

- Approximations for "Soft+Virtual"
- small t (leading terms in Q^2/m_e^2)
- large t (leading terms in m_e^2/Q^2)

- Intergrated hard photon emission
  - such a way that $|T_{Hard}|^2 \Rightarrow \delta_H \times |T_{LO}|^2$

$$\frac{d\sigma}{dQ^2} \Rightarrow \Big(1 + \delta(Q^2)\Big) \times \frac{d\sigma_0}{dQ^2}$$

or

$$\sigma \Rightarrow (1 + \delta) \times \sigma_0$$

Example: approx. rad.corrs

Ong, Kessler (1988)

[Ong, Kessler, Phys.Rev. D38 (1988) 2280]

[Ong, Carimalo, Kessler, Phys.Lett. B142 (1984) 429]

- In a modified form, implemented in GGRESRC

  [Druzhinin, Kardapoltsev, Tayursky, arXiv:1010.5969]

- Used in BaBar data analyses

  [Aubert et al., Phys.Rev. D80 (2009) 052002]

  [del Amo Sanchez at al., Phys.Rev. D84 (2011) 052001]

  [Lees et al., Phys.Rev. D81 (2010) 052010]

A safe approach to rad.corrs

- use exact QED formulae
- no analytic integration of hard photon spectrum
- implement in MC
- make it numerically efficient

Under development in EKHARA MC generator

Summary

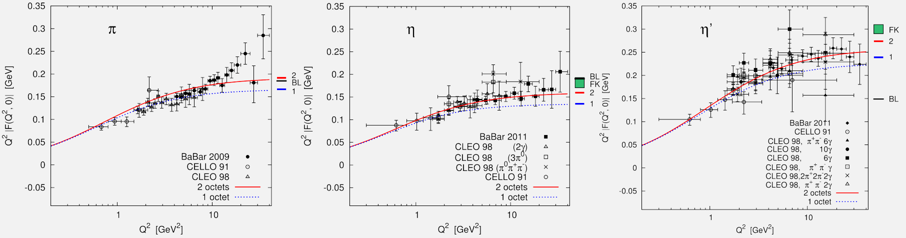
- The $\gamma\gamma$ MC generators are doing well
- Some of them are distributed under CPC licence
- The algorithm lessons from LEP era generators

- Improvement in rad.corrs is needed and foreseen
- 2 and 3 meson cases to be implemented

Spare parts

Transition form factors

π^0 $\qquad$ η $\qquad$ η'



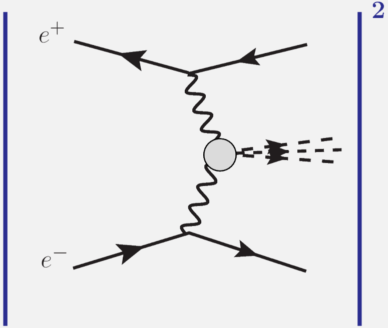
- form factors in resonance effective chiral theory
- implemented in EKHARA

[Czyż, Ivashyn, Korchin, Shekhovtsova, Phys.Rev. D85 (2012) 094010]

`http://prac.us.edu.pl/~ekhara`

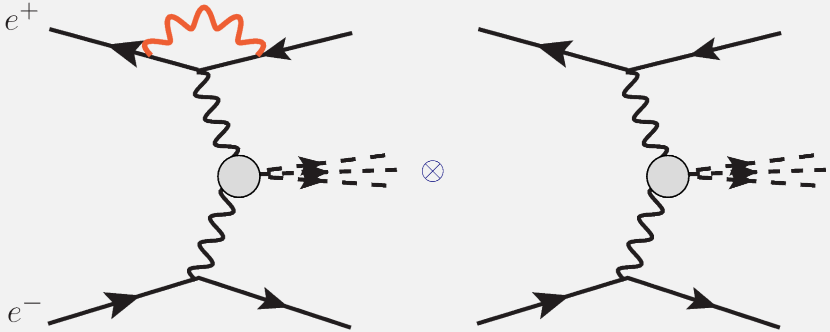
Soft photon emission

$(\cdots) \times$



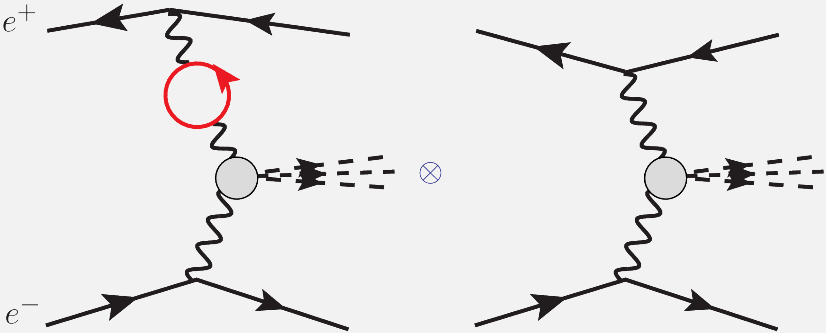
- Soft is what we never observe
- Contains infra-red divergent part
  (to be cancelled by virtual corrections)
- M_0 — separation of hard and soft photon

Virtual. Positron line



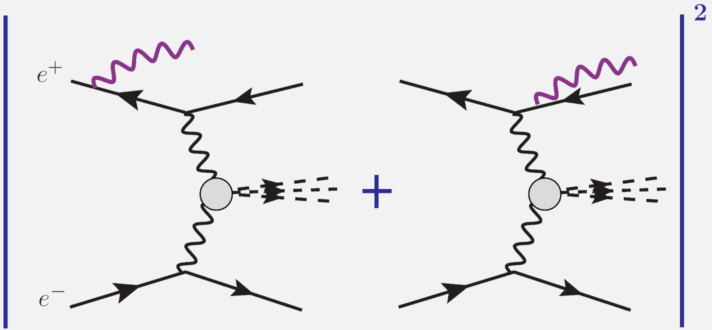
- IR-divergent part cancels by soft corrs
- similar correction for the electron line

Virtual. Vacuum polarization



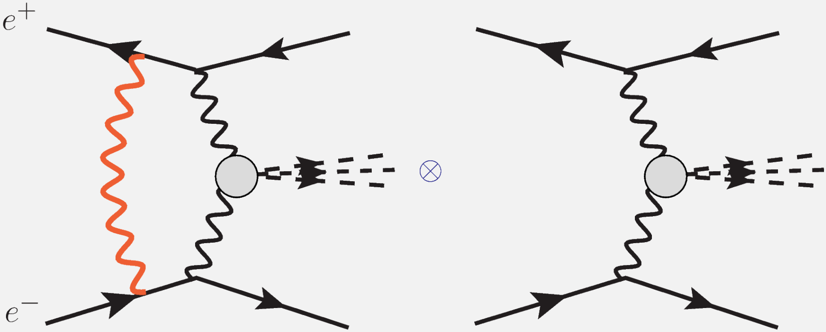
- e^-, μ^-, τ^- loops are there
- hadronic vac.pol. is also there
- similar correction for the electron line

Hard photon emission. Positron line



- M_0 — separation of hard and soft photon (matching)
- +1 particle in the final state
- similar correction for the electron line

Pentabox contribution



“contributions of the five-point functions will always be negligible or irrelevant”

[van Neerven, Vermaseren, Phys.Lett. B142 (1984) 80]

Ong, Kessler. Final formula

Rad.corr for single-tag case

$$\delta = \delta_{V+S} + \delta_{HI} + \delta_{HF}$$
$$= -\frac{\alpha}{\pi}\left(\left(\ln\frac{1}{r_{max}} - \frac{17}{12}\right)(L-1) + \frac{25}{36}\right)$$

✓ depends only on Q^2 (via L) and r_{max}

- $L \equiv \ln\frac{Q^2}{m^2}$
- r_{max} is maximal energy of undetected ISR hard photon normalized to the beam energy, typically: $r_{max} \ll 1$

Example: exact, but integrated

[Landrø, Mork, Olsen, Phys.Rev. D36 (1987) 44]

- Start with the *exact* formulae for the rad.corrs
- Integrate the hard-photon spectrum

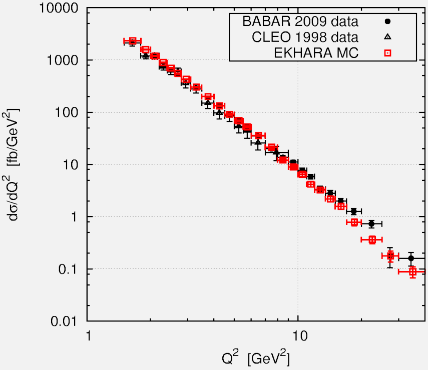
- Total rad.corr is then given only by the *vac.pol.* contributions
  (the rest gets fully cancelled)

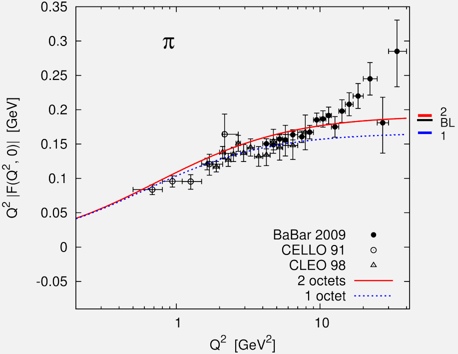
Final formula

$\delta = \delta_{vac.pol.}$

Why integrated results are bad

- intergrated form is good for analytical exercises
- for MC one needs unintegrated expressions





- differential cross section spans more than five orders of magnitude
- integrated rad.corr with small uncertainty can in fact be dramatically biased in the tail

EKHARA rad.cors. Work in progress

- Check independence of result from
  - ✓ IR regulator λ
  - ✓ Soft-Hard matching scale M_0

- Developing efficient mappings
- To compare with GGRESRC